Plasma Processes, Inc.

Phase I SBIR: Slow Flowing Liquid Lithium Using Engineered Surfaces

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Lithium Wall Background

- Reactor studies have identified liquid Li walls as a promising solution to MFE first wall problems
- To date, the use of liquid metal walls has focused on two techniques:
  - Bulk static or fast flowing liquids metals (~1cm thickness)
    - Bulk static liquid Li is only suitable for short-pulse experiments (CDX-U)
    - HHF and long pulse lengths require fast flowing bulk liquid Li to remove heat and limit surface temperature excursions (ALPS and APEX)
    - MHD effects and the ability to deal with tens or hundreds of liters of liquid metal have made implementation of flowing liquid metals difficult
  - Thin lithium films (several thousand Å thickness)
    - LTX and first Li experiments in NSTX
    - Li film acts as a particle pump and substrate provides thermal mass and acts as a heat sink
    - With actively cooled substrates, the heat handling capacity of the thin Li film approach can be extended to long pulse durations

Issues with Thin Li Film Approach

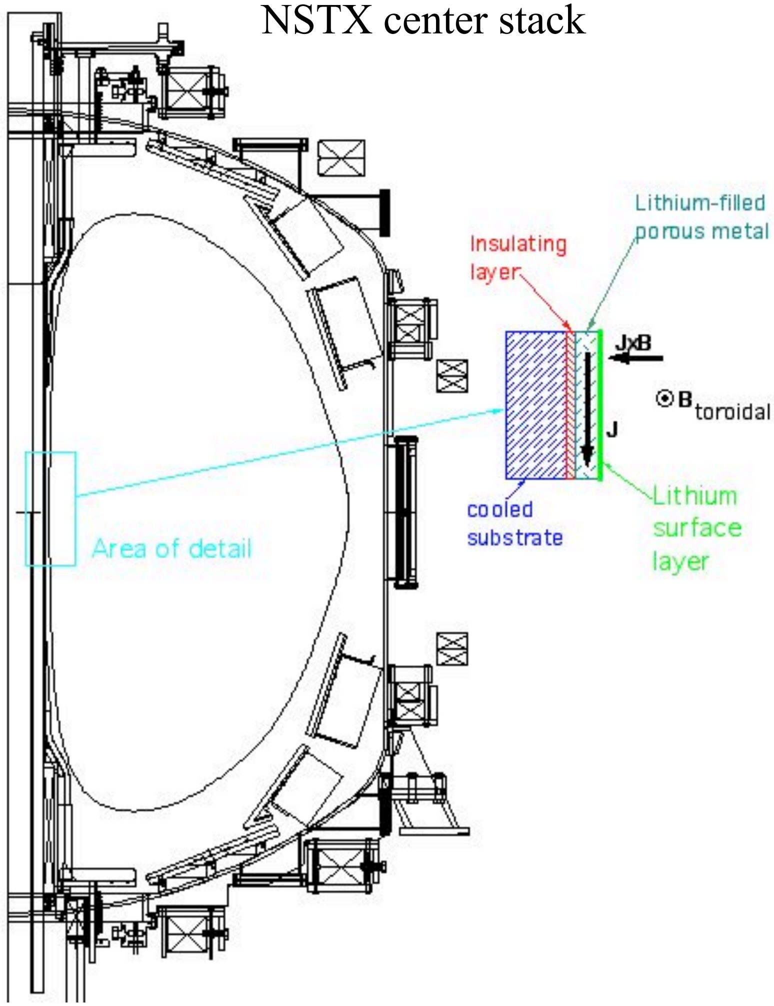
- A single "application" of Li must be capable of pumping the plasma for the entire discharge duration
- Renewal of the Li film is only possible between discharges
- If the discharge endures for many particle confinement times, the Li film will become saturated with hydrogen
- At hydrogen concentrations >10%, hydrogen will no longer be a highly diffusive solute, but will form a hydride
- LiH has a higher m.p. than metallic Li and will remain a solid

Alternative Lithium Film Technique

- Slow flowing “thick” Li film in a porous metal matrix
  - ~mm/sec
  - “thick” ~ 0.25mm
  - Flow driven by thermocapillary forces or J × B
- Heat removal via temperature controlled substrate
  - Only Li film will interact with the edge plasma
  - Low activation ferritic steel or high conductivity copper alloy
  - Gas, other cooling
- For a long pulse device (e.g. ITER) wall lithium only creeps between shots
  - Hydrogen capacity of 0.25mm film is large
  - Local fast Li flow in divertor would provide He ash removal
- Restraint by J × B forces available

Phase I Technical Approach

Example application:
NSTX center stack



- Goal: Demonstrate the feasibility of slow flowing "thick" Li films using engineered surfaces
- PPI is developing engineered surfaces
  - Metallic substrate
  - Thin insulating layer
  - Barrier layer
  - Porous metal layer
- PPPL is performing liquid Li testing
  - Wetting of porous metal
  - Compatibility of insulating and barrier layers (~400C)
  - Lithium flow and restraining tests

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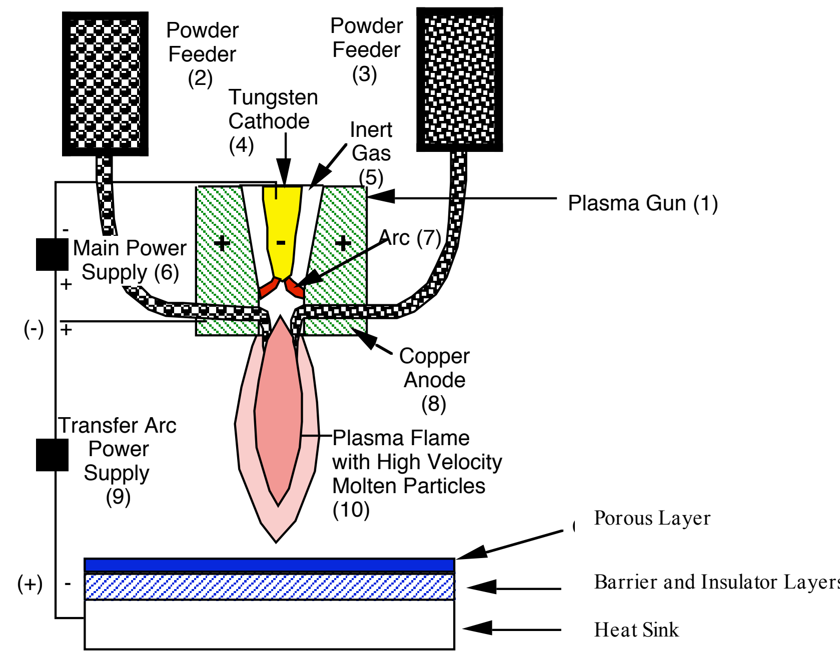
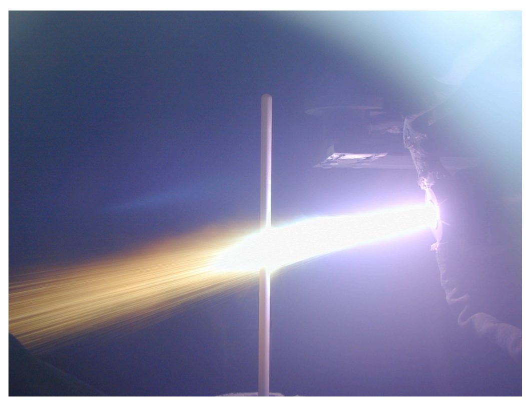
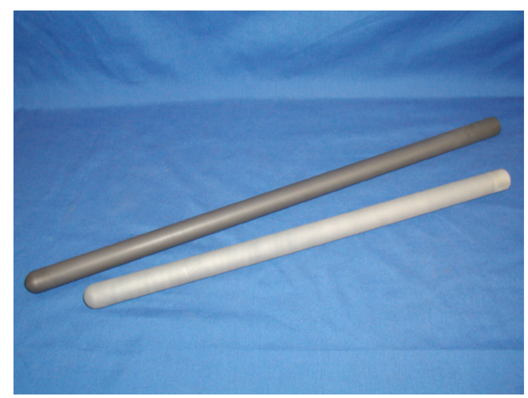
PPI Background

- Plasma Processes, Inc. is a small business that specializes in the development and fabrication of coatings and near-net-shape spray formed structures using Vacuum Plasma Spray (VPS) forming techniques.

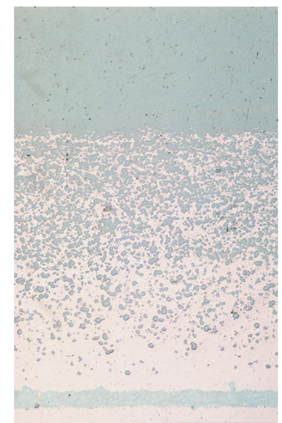


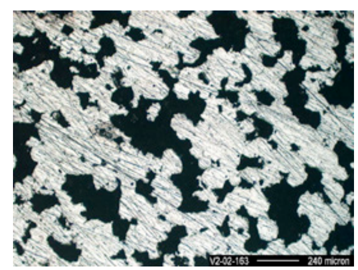




Advantages of VPS Forming Techniques

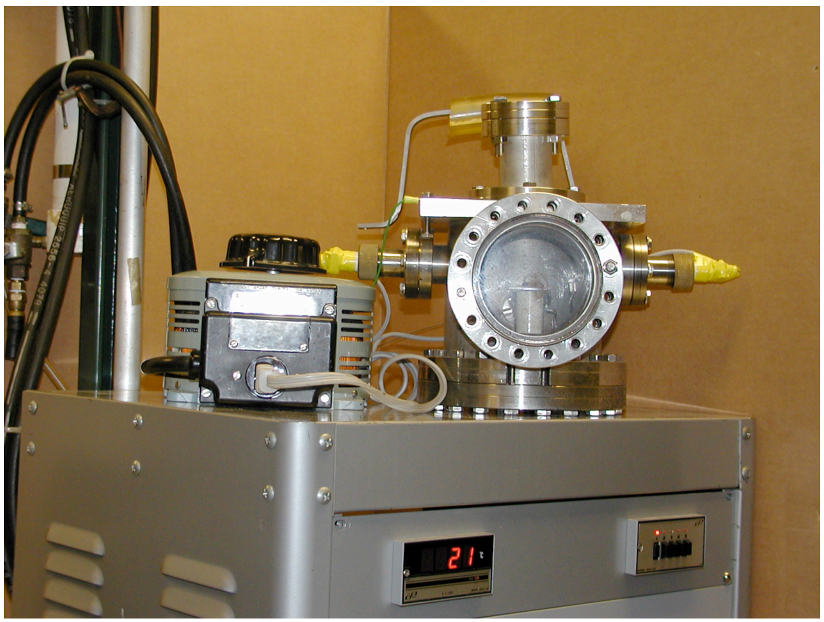
- Processing of oxygen sensitive materials
- Ability to use reactive gases
  - H_2 for O_2 reduction
  - N_2 for nitriding
- High temperature plasma enable processing of high melting temperature materials
  - Refractory metals (e.g., W, Re, Mo, Ta, Nb)
  - Ceramics (Al_2O_3, Y_2O_3, HfN)
  - Carbides (e.g., TaC, HfC)
- CNC control enables contour following and uniform, repeatable deposition thicknesses
- High deposition rates (e.g. >10kg/hour)
- Deposition of alloys and dispersion strengthened materials
- Net shape (near) spray formed components using removable mandrels
- Post-spray heat treatments can result spray formed materials with density >99% and properties equivalent to or exceeding wrought materials
- Ability to tailor the structure of the deposits by varying the spray parameters
  - Porous structures
  - Functional gradient layers for joining materials with dissimilar CTEs
  - Multi-layered structures





Lithium test stands at PPPL

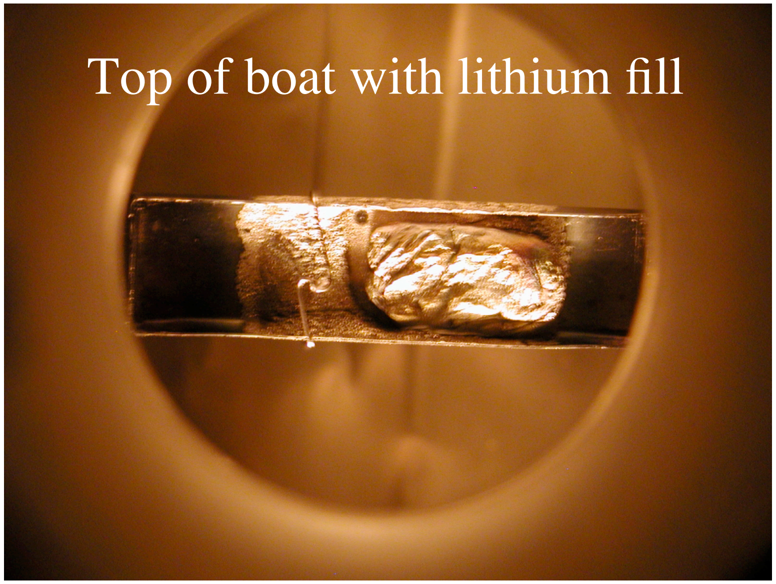
- Large vacuum stand.
  - Presently used for evaporator tests.
  - Can be used for in-vacuum wetting, film transport tests

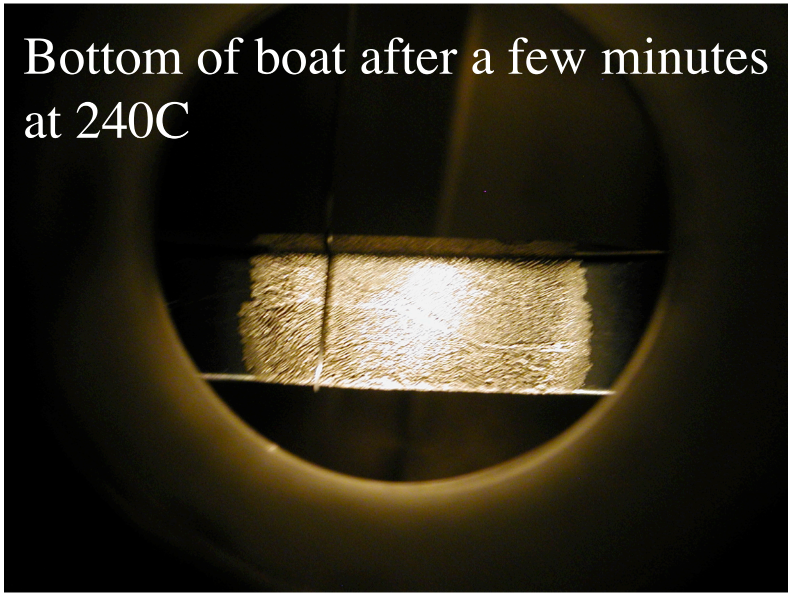


- Small argon-filled chamber for wetting tests.
  - Larger chamber in preparation.

Lithium wetting tests at PPPL

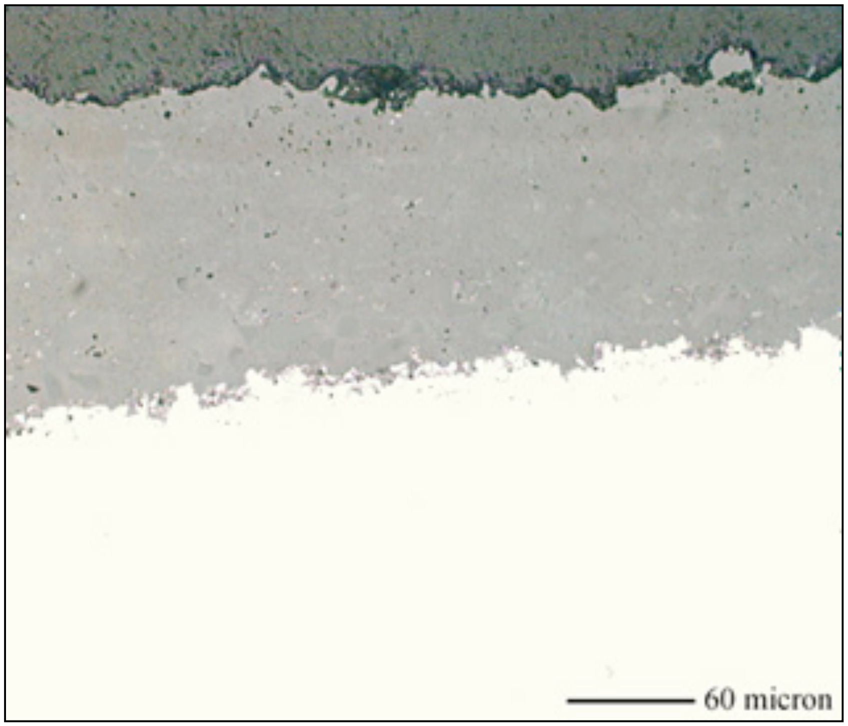
- Tests of tantalum show the lowest wetting temperature (240C)
- Other materials which wet at moderate temperatures include stainless steel (we have primarily worked with 304) and molybdenum.
- Only ceramic PPPL has tested which is suitable for liquid Li service is yttria.
  - Y_2O_3 paint has shown good resistance, but is soft; easily removed from substrate
  - Plasma sprayed coatings of yttria may be very useful as insulators, wetting inhibitors, etc.





View of resistively heated lithium boat in small argon filled chamber

Insulator Layer



- Yttria deposits have been produced on CuCr, 304SS and steel substrates
- Deposits are very dense and well bonded
- Microhardness: 743 VHN @ 200g load
- Additional insulator materials are being evaluated

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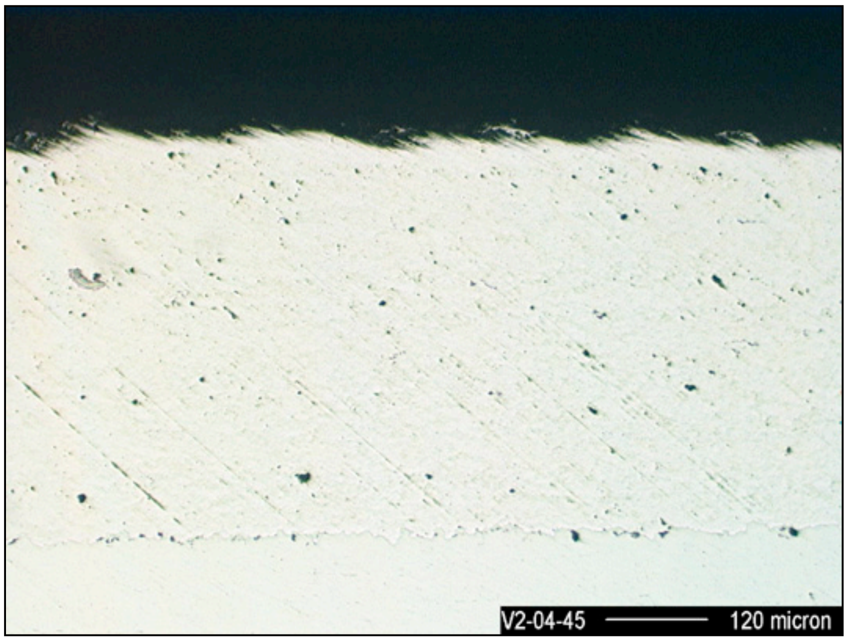
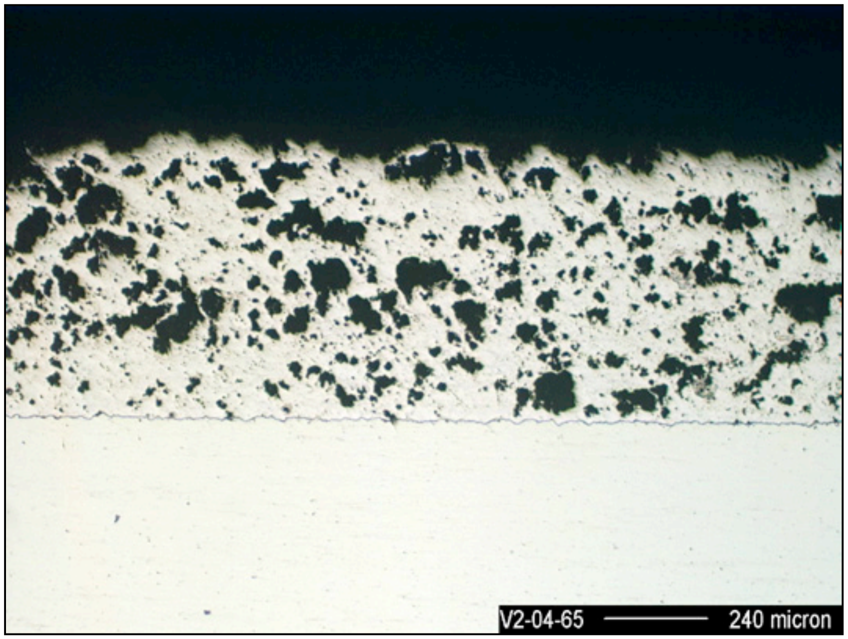
Barrier Layer



- Dense metallic layer
  - Mo
  - SS
- Ceramic layer that is not wet by liquid lithium
  - Yttria could serve as both the insulator layer and the barrier layer

Porous Layer



Porous Mo deposit (~70% dense)

- Porous deposits of W and Mo have been produced
- Previous testing of porous refractory metal deposits have verified the pores are interconnected
- Based on PPPL's preliminary tests, 304SS porous deposits are also being produced

Future Work

- Complete the fabrication of the insulator, barrier and porous layers for wetting and compatibility testing (Dec. 2004)
- Complete the fabrication of engineered surfaces for flow testing (mid-Jan. 2005)
- Complete liquid Li testing (mid-March 2005)
- Analyze results and identify the most promising materials for evaluation during Phase II (April 2005)
- During Phase II, develop the concept for testing in a spherical torus such as LTX or NSTX (2005-2007)